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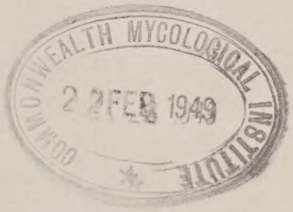
PRODUCTION IN CALIFORNIA OF SNAP-BEAN SEED FREE FROM BLIGHT AND ANTHRACNOSE

W. W. MACKIE, WILLIAM C. SNYDER, and FRANCIS L. SMITH



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PRODUCTION IN CALIFORNIA OF SNAP-BEAN SEED FREE FROM BLIGHT AND ANTHRACNOSE[1]

W. W. MACKIE,[2] WILLIAM C. SNYDER,[3] AND FRANCIS L. SMITH[4]

INTRODUCTION

PERHAPS no two diseases have been consistently more destructive to beans (*Phaseolus vulgaris* L.) in the United States than anthracnose, caused by *Colletotrichum lindemuthianum* (Sacc. and Magn.) Briosi and Cav., and bacterial blight,[5] caused by *Bacterium phaseoli* E. F. S., *Bact. medicaginis* var. *phaseolicola* (Burk.) Link and Hull, and *Bact. flaccumfaciens* Hedges.

Numerous records of nearly half a century attest the seriousness of these diseases on crops grown for market, canning, and the dry-bean trade. In New York the importance of anthracnose was recognized in the 1890's (Beach, 1892).[6] Later a study of anthracnose and blight was begun in that state because "serious diseases have threatened the great bean industry of New York" (Whetzel, 1906). About the same time, anthracnose was regarded as "the greatest drawback to the growing of beans in Louisiana" (Edgerton, 1909); and subsequently blight was found to be equally important (Edgerton and Moreland, 1913). Michigan also was experiencing severe losses from these diseases and had started work on them (Muncie, 1917).

Serious outbreaks of anthracnose and blight in epidemic form occurred throughout the Midwest, East, and South between 1916 and 1919, with losses running to 25 per cent, and higher, in some states. In 1918 (Plant Disease Reporter, 1918) anthracnose was "very common, widespread and destructive" in Maine; "generally distributed and frequently destructive" in New Hampshire. The same year, blight was "general throughout" Massachusetts, "present in 75 per cent of the bean fields and causing considerable damage" in New York; "present everywhere and doing much damage" in Michigan. Blight was also "widespread" in Minnesota; and Colorado suffered severe damage, with "some fields . . . entirely destroyed." The following year (Plant Disease Reporter, 1919) Florida reported that "beans show a very heavy infection of blight." In Louisiana infection by anthracnose and blight was "severe"; these diseases were "common everywhere and doing considerable damage." They were also "very general over the state" of Mississippi.

The next serious outbreak came in the late 1920's, when blight was "very abundant on the Green Refugee variety of canning beans" in New York during 1926, causing "10 to 15 per cent damage to the crop" (Plant Disease Reporter, 1926). The losses in Michigan in 1924 were "100 per cent in some fields, especially canning varieties," and anthracnose infection in Wisconsin was "more than usual" (Plant Disease Reporter, 1924). The blight in Minne-

[1] Received for publication April 15, 1944.

[2] Agronomist in the Experiment Station.

[3] Associate Professor of Plant Pathology and Associate Plant Pathologist in the Experiment Station.

[4] Assistant Agronomist in the Experiment Station.

[5] The terms *bacterial blight* and *blight* as used throughout this bulletin apply indiscriminately to common blight, halo blight, and bacterial wilt.

[6] See "Literature Cited" for complete data on citations, referred to in the text by author and date of publication.

sota in 1929 was "very destructive, most fields showing 100 per cent infection" (Plant Disease Reporter, 1929). In bean-disease surveys made in the seed-producing western states about this time (Plant Disease Reporter, 1930*a*), blight was found "sparingly in Wyoming, Utah and Colorado and slightly more abundant in Montana" but was "not found in Idaho and California" in 1929. Again in 1930 "the bacterial blights were not found in California"; but that year they were seen in Idaho, as well as in the other western bean-growing states (Plant Disease Reporter, 1930*b*), in small amounts.

During most of the 1930's anthracnose and blight were in general less serious than in the preceding decade, except in occasional instances or in restricted areas. This did not mean, however, that the greatly increased knowledge of these diseases gained during the last three decades (Whetzel, 1908; Edgerton and Moreland, 1913; Muncie, 1917; Rapp, 1920; Burkholder, 1921, 1926, 1930; Hedges, 1926; Zaumeyer, 1930) had been transferred into effective control, for new widespread outbreaks again appeared, starting in the last part of the 1930's and running into the 1940's.

This most recent outbreak seemed to have been touched off by an epidemic in the seed-bean area of Wyoming during 1937, when "bacterial blight of beans was very destructive" (Plant Disease Reporter, 1937*a*). The following year (Plant Disease Reporter, 1938*a*) "garden beans grown for canning purposes in western Nebraska showed a loss of 60 to 65 per cent due to halo blight"; and in Colorado "37 per cent of the field bean and 33 per cent of the garden bean acreage was seriously infected with the bacterial blights." In addition, "bean blight caused extensive damage to commercial bean fields throughout Illinois, northern Indiana, and southern Michigan." Anthracnose again became important in 1938, causing "severe losses in both home garden and commercial plantings" in Massachusetts. More recently, in 1940, Florida reported (Plant Disease Reporter, 1940) that "halo blight of beans was very severe.... Many fields were inspected and only 1 or 2 were observed where halo blight was not severe." In Texas in 1941, "bacterial blight was destructive in many fields, causing total loss of early pickings" (Plant Disease Reporter, 1941*b*). On the east coast "a tremendous amount of bean anthracnose" was observed in victory gardens in 1942 (Plant Disease Reporter, 1942*a*). Nebraska the same year reported that "beans in many small, home gardens were completely destroyed by bacterial halo blight" (Plant Disease Reporter, 1942*b*), while in New York anthracnose "appeared in almost epidemic form in 1942. . . . The disease spread rapidly, and in some cases destroyed whole fields completely" (Plant Disease Reporter, 1943*a*).

In 1943 (Plant Disease Reporter, 1943*b*) bacterial blight, anthracnose, or both, were reported from twenty-four states, including Montana, Colorado, Wyoming, Utah, Idaho, Arizona, and New Mexico in the West, Michigan and New York in the East.

Wyoming apparently experienced another blight year in 1944. In a survey of garden-bean varieties grown for seed production that year (Plant Disease Reporter, 1944), it was reported that "bacterial halo blight was general over the entire state of Wyoming."

These recorded field observations indicate the seriousness of anthracnose and blight, in past as well as in recent years, in the humid bean-growing

regions of the United States. For considerable periods, these diseases have temporarily subsided; but eventually they have reappeared with the same suddenness and destructiveness as before. They are seed-borne. As long as growers continue to plant infected seed, epidemics of anthracnose and blight are sure to occur.

Clearly, the first essential in control is the use of noninfected seed. This bulletin will consider solely the possible sources of such seed and the requirements for growing it successfully.

DESCRIPTION OF DISEASES

Bean Anthracnose.—An old disease of beans, world-wide in its occurrence and destructive under wet conditions, anthracnose may still be classed as a major problem, although western-grown seed has greatly reduced its importance. The causal fungus, *Colletotrichum lindemuthianum,* produces conspicuous dark-brown craterlike lesions on stems and pods and reddish lesions on veins on the underside of the leaves of the common bean (*Phaseolus vulgaris* L.), tepary bean (*P. acutifolius* var. *latifolius* Freeman), and to a lesser extent of lima bean (*P. lunatus* L.), multiflorus, or scarlet runner, bean (*P. coccineus* L.), and mung bean (*P. aureus* Roxb.). In moist periods when the fungus is sporulating, these sunken lesions as well as those on the veins bear gelatinous masses of flesh-colored spores responsible for spreading the disease. The spores depend upon free water for their conveyance to other plants and plant parts, and are wind-borne short distances in the field by droplets of spattering rain that carry a suspension of spores. Insects aid in the spread of spores, as do bean pickers who work while the plants are wet. The fungus may contaminate the surface of the seed before or possibly during threshing, and in addition it may actually invade the seed while in the pod and pass beyond the reach of fungicidal dusts or dips. Although the organism may live over in bean refuse of one infected crop to the following season, it is not a soil fungus and soon dies out in the absence of the crop. Land that has grown an infected crop of beans may therefore be freed of the fungus through a crop rotation in which beans are kept off the land for two to four years, or until all bean refuse of the infected crop has decomposed. Infected seed, then, is the chief source of infection and provides a means of distribution both locally and over long distances.

The alpha, beta, and gamma strains of the fungus are the best known (Burkholder, 1923). Although some varieties of beans are more resistant to certain strains than are others, the best protection against anthracnose is still the use of disease-free seed on noninfested land.

Bacterial Blight of Beans.—As a group, the bacterial diseases of beans continue to be important in the northern tier of states, and especially in the South and the East, as well as in various other parts of the world. Frequently, they appear in certain of the Rocky Mountain states where some of the "western-grown" bean seed is produced. Most important are common bacterial blight caused by *Bacterium phaseoli,* and halo blight caused by *Bact. medicaginis* var. *phaseolicola.* A third disease, bacterial wilt, has as its cause *Bact. flaccumfaciens.* Still other species and varieties of bacteria capable of attacking beans have been described (Burkholder, 1930). Many species of bean (*Phaseolus*) and certain other legumes are susceptible to one or more of these bacterial

diseases—for example, the common beans, lima beans, mung beans, soybeans (*Glycene Max Merr.*), cowpea (*Vigna sinensis* Endl.), the kudzu-vine (*Pueraria Thunbergiana* [Sieb. and Zucc.] Benth.), and the wild bean *Strophostyles helvola* (L.) Britton (Gardner, 1924).

Although several different species of bacteria are involved, they are similar in many ways in their behavior towards the host, in the manner of infection, and in the requirements for their development in the plant. All are distinctly wet-weather organisms, with essentially the same life histories and host relations, and are abundantly carried in and on the seed from infected plants. Like the anthracnose fungus, they do not survive in the soil after diseased refuse has disintegrated; infested land can be rid of them if three or four crops of nonsusceptible plants follow the beans. Unlike anthracnose, the bacteria are able at times to advance through internal tissues within the plant, after infection has taken place. These diseases, therefore, may progress somewhat even during periods of unfavorable external conditions, infection having taken place. They may be active at somewhat higher temperatures than anthracnose.

The bacterial diseases are characterized by water-soaked lesions on leaves, stems, and pods. The affected leaf tissue soon becomes brown and when dry is often frayed during winds, so that the leaf appears tattered. Old, inactive infection on leaves is therefore often difficult to recognize in the field. Stem and pod lesions may become brick red and slightly sunken; bacterial ooze or dry crusts of such ooze may accumulate on the lesions. When the bacteria gain entrance to the vascular system, wilting and stunting may occur—the symptoms most characteristic of bacterial wilt. The most distinctive feature of halo blight is the yellowish or chlorotic halo surrounding the leaf lesions.

Spread of the bacterial diseases in the field is accomplished by transference of bacterial ooze from the surface of infected plants to healthy plants; the carrier may be spattering rain, moving water, insects, or workers and equipment moving through the field while the plants are wet.

The bacteria gain access to the seed while it is in the pod or during threshing. They may be carried internally, externally, or in both ways. Prevention depends again chiefly upon the use of noninfected seed, coupled with crop rotation.

MEANS OF CONTROLLING SEED-BORNE DISEASES

The causal agent (fungus or bacterium) of any of these diseases may establish itself within the seed and there remain dormant until germination. At that time it may initiate new infections on the seedling plants; and eventually, if conditions favor the causal agent, it will bring about losses to the resulting crop. These diseases depend upon rain or other free moisture for their development and spread.

Three general approaches to control have been evident: first, the use of seed treatments before planting and of sprays and dusts after emergence; second, the use of resistant varieties; third, the use of disease-free seed in combination with crop rotation.

All attempts at commercial control of the seed-borne diseases of beans by seed treatments have failed, largely because the disease agent located within

the seed coats could not be destroyed without damage to the seed. Early in the history of anthracnose and bacterial blight in this country, extensive tests were made with various dry chemicals, liquid chemicals, dry-heat and hot-water seed treatments; but no real success was achieved (Beach, 1892; Halsted, 1901; Fulton, 1908; Muncie, 1917; Rapp, 1920). More recently the seriousness of seed-borne bacterial blights has resulted in renewed efforts of this kind (Person and Edgerton, 1939; Kreitlow, 1940), but still without fully satisfactory results. Likewise, control of blights and anthracnose in the field by means of sprays or dusts has not proved feasible (Whetzel, 1908; Rapp, 1920; Burkholder, 1930; Person and Edgerton, 1939). The aging of infected seed for two or three years has been suggested as a means of eliminating infection in bean seed (Rapp, 1920); but aside from being impracticable this method cannot be considered safe, since virulent bacteria have been recovered in a living condition from infected bean seed three to five years old (Burkholder, 1930; Hedges, 1926).

Despite many attempts, no one has offered a commercial variety of common beans that is immune to these diseases. Varieties differ considerably, however, in the degree of susceptibility shown; and some are resistant to certain strains of the anthracnose fungus (Barrus, 1911; Rands and Brotherton, 1925; Burkholder and Zaleski, 1932). Eventually, perhaps, selections will be forthcoming in the most popular varieties of beans that are at least highly resistant to the seed-borne diseases under consideration. This ideal, however, is not likely to be realized for all the important varieties for some time, owing to the scarcity of satisfactory parent stocks highly resistant to the various diseases, the time required to complete a breeding program, the constantly changing requirements for the type of bean demanded by the trade, and the likelihood that new strains eventually may appear and attack some of the new varieties.

Thus far the most promising method, from the standpoint of immediate results in controlling anthracnose and blight, is the use of seed known to be free of these diseases, with a program of crop rotation.

CONDITIONS UNDER WHICH SEED INFECTION OCCURS

Anthracnose and blight of bean are wet-weather troubles; their spread and development in vegetative as well as in fruiting parts of the plant depend largely upon the presence of free moisture, coupled with suitable temperatures. If the conditions necessary for infection from diseased seed or from crop refuse are not present, seed harvested from the field remains clean. Should primary infection take place on the seedlings, yet conditions for the remainder of the season be unfavorable to these organisms, the seed crop may still escape. Almost certainly, therefore, the occurrence of such diseases of bean as anthracnose and bacterial blight hinges upon the weather, provided the causal organisms are present—that is, in crop refuse or in the planted seed. Although these diseases occur in most bean-growing regions, they have not been found in the principal bean areas of California during the dry summer months.

With rainfall playing an essential role, one may logically assume that beans continually grown during rainless periods should be free of blight and anthracnose, even though the original seed be contaminated with the causal

organisms. This is the result in practice. Even if primary infection should take place from diseased seed before emergence, secondary spread after emergence fails to occur in a rain-free climate, and the causal agent tends to die out.

Anthracnose and blight can be avoided by the bean grower in rainy climates, provided the source of primary inoculum is eliminated. Usually this means the elimination of infection from the seed he uses. It was to this purpose that bean-seed production moved westward; and western-grown seed has proved to be practically free from anthracnose (Plant Disease Reporter, 1930*a*). Even in the West, however, most states have enough summer rainfall to permit blight to reach the seed in some years (Plant Disease Reporter, 1930*b*). But in California, because of the rainless summers, anthracnose and blight fail to become established in the seed-growing areas.

CLIMATE IN RELATION TO THE PRODUCTION OF CLEAN SEED

Since these seed-borne diseases of beans require wet weather during the growing season for their propagation, a knowledge of the amounts of rainfall in areas that grow seed beans becomes highly important.

Table 1 gives the monthly precipitation in inches for several locations in eight bean-growing states, based on long-term averages. The period considered for each represents the critical months of June, July, August, and September. The rainfall figures for these months are in heavy type, the total rainfall for the 4-month period appears in the right-hand column of the table. A marked contrast between the different bean-growing areas is evident. In New York and Michigan the rainfall during the bean-growing season ranges from 10 to 13 inches. In the West it is much less, but still considerable in some places—5 to 6 inches in Montana, 3 to 6 in Colorado, 3 to more than 4 in Wyoming and Utah, and nearly 2 to 3 in Idaho. In years of low rainfall certain of these western states may produce clean seed even in the presence of some inoculum. Disease-free-seed production in wet years, on the other hand, rests upon the use of noninfected seed on noninfested land. A further comparison of California's dry bean-growing season with the more or less rainy bean-growing seasons of other states is made possible by the following data:

Bean-growing states	Average total rainfall for 4-month summer period, in inches
Wisconsin	13.6
New York	12.0
Michigan	11.4
New Mexico	8.9
Montana	6.2
Arizona	5.9
Washington	5.4
Colorado	5.0
Oregon	3.8
Wyoming	3.7
Utah	3.5
Idaho	2.9
California	0.4

TABLE 1

AVERAGE MONTHLY PRECIPITATION IN EIGHT STATES, WITH SPECIAL REFERENCE TO THAT OCCURRING DURING THE BEAN-GROWING SEASON IN ESTABLISHED BEAN-PRODUCING AREAS*

State and weather station	Years of record	Average precipitation						Total during growing season,† June through Sept.
		May	June	July	Aug.	Sept.	Oct.	
	number	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*
New York:								
Letchwork Park	25	3.25	3.16	2.88	2.76	2.73	2.48	11.53
Linden	15	2.57	3.59	3.79	3.35	2.79	3.31	13.52
Rochester	40	2.50	2.84	2.84	2.71	2.54	2.65	10.93
Michigan:								
Arbela	28	4.12	3.15	3.30	3.09	3.22	2.67	12.76
Harbor Beach	40	2.96	2.67	2.53	2.47	2.59	2.42	10.26
Saginaw	40	3.52	2.71	2.88	2.85	2.84	2.52	11.28
Montana:								
Agricultural College	40	2.81	2.40	1.37	1.13	1.65	1.54	6.55
Billings No. 2	34	2.33	2.20	1.34	0.97	1.22	1.24	5.73
Miles City	40	1.89	2.42	1.67	1.20	1.07	0.83	6.36
Colorado:								
Grand Junction	40	0.79	0.45	0.70	1.11	0.94	0.88	3.20
Greeley	39	2.28	1.57	1.69	1.15	1.13	0.98	5.54
Mancos	21	1.26	0.88	1.89	2.06	1.61	1.62	6.44
Wyoming:								
Riverton	24	1.95	1.10	1.06	0.70	0.91	1.20	3.77
Powell	32	0.97	1.15	0.65	0.50	0.78	0.38	3.08
Clark	30	1.77	1.39	1.24	0.80	1.02	0.85	4.45
Utah:								
Spanish Fork	30	1.72	0.66	0.91	0.92	1.07	1.60	3.56
Farmington	38	2.19	0.92	0.74	0.93	1.22	1.66	3.81
Logan	40	1.91	0.83	0.65	0.70	1.14	1.74	3.32
Idaho:								
Lewiston	40	1.34	1.28	0.47	0.56	0.87	1.15	3.18
Moscow	40	1.71	1.45	0.55	0.64	1.13	1.69	3.77
Twin Falls	33	1.06	0.72	0.35	0.24	0.52	0.93	1.83
California:								
Colusa	36	0.41	0.24	0.00	0.01	0.37	0.56	0.62
King City	40	0.28	0.07	0.01	0.01	0.17	0.32	0.26
Marysville	40	0.74	0.00	0.27	0.02	0.35	1.02	0.64
Merced	40	0.44	0.09	0.01	0.02	0.17	0.53	0.29
Riverside	40	0.46	0.04	0.01	0.16	0.19	0.68	0.40
Sacramento	40	0.54	0.16	0.00	0.00	0.30	0.80	0.46
Salinas	40	0.45	0.10	0.02	0.03	0.29	0.43	0.44
Santa Maria	35	0.48	0.11	0.00	0.04	0.20	0.72	0.35
Stockton	40	0.58	0.12	0.00	0.01	0.29	0.64	0.42
Tustin	40	0.42	0.07	0.00	0.02	0.14	0.65	0.23
Ventura	28	0.31	0.08	0.00	0.02	0.20	0.71	0.30

* Taken from: United States Department of Agriculture. Climate and Man. U. S. Dept. Yearbook of Agr. 1941 :751–1201.

† The four months June, July, August, and September have been taken to be most representative of the season during which seed beans are normally grown.

Table 1 shows why bacterial blight may occur in the bean areas in question and why it does not occur in California seed areas. The total rainfall during the bean-growing months in eleven bean districts in California is not over 0.64 inch for the 4-month period, and for most localities it is less. The nearest competitor in low rainfall among the states represented is the Twin Falls area in Idaho, where the thirty-three-year average rainfall for the 4 months June through September is 1.83. This is still two to six times that of the California areas on the basis of long-time averages. The northern Idaho sections, however, have more than 3 inches; and blight is known to be more prevalent there than in southern Idaho (Murphy, 1940).

Not only is the seed-bean season drier in California, but the summer dry period is longer than in other bean-growing states. This situation is illustrated in table 1 by the figures on average precipitation given for May and October, which precede and follow, respectively, the principal seed-growing months. The average of the May rainfall for the Idaho stations, for example, is 1.37 inches against 0.46 inch for the California stations, a ratio of about 3 to 1; and in October the rainfall at the Idaho stations averages 1.26 inches against 0.64 inch in California, a ratio of about 2 to 1.

California is remarkably consistent in the absence of summer rain. Even in extremely wet years such as 1940 and 1941, when the annual precipitation was near the highest ever recorded in the state's history, the summer (4 months) conformed fairly closely to the long-term pattern and had no more rain than usual either year. In other words, the excess California rainfall in unusually wet years comes during the winter, and little more occurs during the bean-growing season than in dry years. The rainfall at Twin Falls, Idaho, however, during the same periods in 1940 and 1941, was 3.54 and 2.98 inches, almost double the normal amount. At Moscow, in northern Idaho, the corresponding figures were 6.03 and 7.24 inches, nearly twice the forty-year average. Blight is known to develop and spread under rainfall of such magnitudes as these.

These figures are in contrast to the 0.23 and 0.37 inch, respectively, of rainfall at Salinas for the 4-month periods in 1940 and 1941, and 0.0 and 0.21 inch correspondingly for Marysville, both these stations being representative of California bean-growing areas.

The high dependability with which dry summers occur in California, even during years of exceptionally large total annual rainfall, does not appear to be equaled in any of the other bean-seed-producing states.

Data in table 1, viewed in the light of field experience, suggest that an average summer rainfall of more than 3 inches is not conducive to the consistent production of clean seed, in the presence of disease inoculum. Rainfall of 1 to 3 inches in the same period may represent the borderline condition for these diseases, whereas less than 1 inch would seem to insure escape from any spread of infection.

With the single exception of California (according to published records), one or more of the bacterial diseases occur in bean fields of all seed-producing states, sometimes in amounts destructive to the crop; and anthracnose, likewise, occurs in some of them. But even slight infection in a seed field may have disastrous results when the seed produced is sown in a wet climate, particularly in such states of abundant rainfall as Louisiana and Florida. On this basis,

California apparently offers the seedman an unusual opportunity for maintaining disease-free seed stock of all beans susceptible to wet-weather seed-borne troubles, if not indeed for multiplying such stocks to meet the country's demand for all seeds of snap beans. Certainly the bean growers in climates favorable to blight and anthracnose would find an unusual opportunity for beginning each season with a new supply of dependably clean seed from California, seed protected from disease by a natural climatic monopoly.

Hybridization in Relation to Pure Seed.—Some hybridization between bean varieties occurs in the field, depending somewhat upon the climatic environment. Cross fertilization in lima beans is known to take place in the tropics of Central America (Mackie, 1943) and to occur in amounts as high as 82.9 per cent in Maryland (Magruder and Webster, 1939) and over 50 per cent in Illinois (Huelson, 1939). The evidence regarding common beans indicates a low rate of hybridization in California. At Berkeley 60,000 plants of common beans yielded only 8 hybrids, while in another field 50 field hybrids were found in 4,136 plants (Mackie and Smith, 1935). This infrequency of field hybridization is due, apparently, to the rainless period at blossoming time, which favors early maturity of pollen and complete fertilization before the flowers open and become accessible to common insect pollinators.

The low percentage of field hybridization in beans under California conditions is employed by some eastern plant breeders to maintain the purity of varieties that are being increased for seed purposes.

RECORDS OF ANTHRACNOSE AND BLIGHT IN CALIFORNIA

The occurrences of anthracnose and blight in California are rare, mostly limited to very small plantings or home gardens started before the cessation of the rainy season or watered by overhead sprinkling; and all are outside the seed-producing areas shown in figure 1.

Anthracnose of bean was found in a small backyard garden in the seashore town of Pacific Grove in 1938 (Plant Disease Reporter, 1938*b*). As inquiry revealed, the gardener had sent east for his bean seeds and had watered the plants with overhead sprinkling, thereby making up for the lack of rain that normally affords protection against this disease in California. Anthracnose has also been found in a small truck-garden district on the coast just south of San Francisco, near Colma (Plant Disease Reporter, 1941*a*). Because of the hilly terrain these truck gardens are often irrigated by sprinkling systems. The overhead watering, combined with favorable temperatures, has been responsible for the occasional appearance of the disease in this locality. Again, in 1944 (Plant Disease Reporter, 1945) anthracnose was found in a small planting of wax beans grown for the early market near Soquel on the coast. The seed, traced to midwestern origin, had been planted during the rainy season, in March. When such seed is grown during the summer, anthracnose does not appear.

Well-authenticated cases of the bacterial blights are also rare in California. Bacterial blight was reported once by Smith (1942), who found it in 1939 on White Kidney beans grown from eastern seed; and it was seen on lima beans in Los Angeles County in 1936 (Plant Disease Reporter, 1937*b*). Two other

records[7] of the disease in the state appeared in the 1930's. One of these was made in a 6-week-old planting of Dwarf Horticultural and brown-seeded Kentucky Wonder beans on a coastal hillside near Pismo Beach, San Luis Obispo County, March 22, 1934. Primary (seed-borne) bacterial blight was observed to the extent of 1 to 2 per cent. No secondary blight was observed. This planting was obviously from diseased seed and out of season, having been started in the midst of the rainy period. It cannot legitimately be considered, therefore, in connection with the occurrence of blight in California bean-seed fields. The other case was in the Butte County foothills, near Paradise, where primary bacterial blight was found June 23, 1939, in a home-garden planting. Apparently this also represented an out-of-season planting; certainly it was outside the bean-seed-growing district.

In 1944 infection with blight was discovered in a small garden planting of Stringless Green Pod at Dorris, near the Oregon border (Plant Disease Reporter, 1945). Under the wet conditions prevailing there, some secondary spread of the bacterial infection had taken place on the leaves but not on the young pods. This instance illustrates the importance of blight-free seed even to California growers in mountainous or other areas where climatic conditions permit spread from primary seed-borne infection.

A trace of primary bacterial blight was detected in an experimental planting of diseased seed at Berkeley in 1944. One lot of French Horticultural beans, known to be heavily infected with bacterial blight, was sent from the East for use here in a trial planting. In 300 feet of row planted in May, three plants each developed 1 to 4 small primary lesions on the first leaves. No secondary spread to leaves or to pods occurred during the season from these lesions, but two plants developed internal stem infection and cankers that girdled the stems at the ground level. These plants partially broke over at the point of the cankers, but each matured a few pods. Although no symptoms developed in the pods or seeds on these two plants, possibly one or more seeds may have been contaminated. Conceivably, an occasional seed might in this way still carry infection at the end of the first season, during which a heavily infected seed stock is grown for cleanup; this possibility should caution seed growers against assuming that one season in California will always be sufficient to free blight-infected seed stocks from all infection.

For years many bean-seed lots have been brought into California from other states for multiplication and for the elimination of seed-borne diseases. Such fields, often started from infected seed, have been watched for bacterial blights and anthracnose; yet no outbreaks in commercial plantings are on record in the files of the California State Department of Agriculture Bureau of Plant Pathology[8] or the files of the University of California Division of Plant Pathology. Nor has a single case of either anthracnose or bacterial blight been seen in the field during several seasons of inspecting beans for certification, according to at least one experienced inspector.[9]

Thus far neither bean anthracnose nor a bacterial blight of bean has been recorded in California in connection with fields of seed beans, of either com-

[7] These unpublished records have been supplied the writers through the kindness of Dr. J. B. Kendrick, University of California, Division of Plant Pathology, Davis, California.
[8] Correspondence from Dr. M. R. Harris, December 10, 1942.
[9] Correspondence from Dr. J. F. L. Childs, December 10, 1942.

mon beans or lima beans grown during the season indicated in table 1. These diseases have been found in California only on rare occasions, and then only where infected seed has been planted out of season and during the rainy period, or in home gardens where overhead sprinkling presumably may have been resorted to. Although primary infection may perhaps sometimes occur undetected in California seed fields from imported, infected seed, secondary infection is apparently unable to take place under the dry conditions that prevail.

Conceivably, when bean seed infected with bacterial blight is planted in California, an occasional internally infected plant may develop and survive long enough to produce a few seeds, certain of which could bear infection. Such a possibility could perhaps be considered where heavily infected seed is being grown the first season for the purpose of freeing it from infection. Out-of-state seedsmen, however, who have sent infected seed to California to produce a crop free from anthracnose or blight have observed no further infection. In any event, the problem being considered here is merely the renovation of bean seed in one season (from the disease standpoint), not the greater enterprise of producing consistently and dependably blight-free and anthracnose-free seed beans of high quality, on a large scale, from seed stocks maintained in California. But to avoid the possibility that bacterial blight might not be eliminated from an imported, infected seed stock in a single season, it is recommended that the seed be grown in California for several successive seasons before being exported for use in a wet climate.

AREAS IN CALIFORNIA ADAPTED TO THE PRODUCTION OF DISEASE-FREE SEED

The United States acreage of snap-bean seed in 1941, except lima beans, compiled from Agricultural Marketing Service,[10] are as follows:

Kind of seed	1939	1940	1941	1942	4-year average
Dwarf green beans	21,866	26,396	36,628	49,849	33,685
Dwarf wax beans	5,478	4,906	6,662	8,669	6,429
Pole beans	3,435	4,634	5,538	7,741	5,337
Total	30,779	35,936	48,828	66,259	45,451

Thus the production of snap-bean seed is an industry occupying about 46,000 acres, only a relatively small part of which has been grown in California up to the present. The California acreage has been rapidly increasing, however, in the last two or three years—evidence that the advantages of California-grown seed are being recognized.

Figure 1, an outline map of California, represents by shaded areas those parts where snap beans have been grown or where other varieties of common beans are now successfully produced.

The largest area is in the Sacramento Valley and the northern San Joaquin Valley, extending from Vina in Tehama County to the west side of the San Joaquin Valley in Merced County. Three other areas are shown: the Santa Clara Valley in Santa Clara County, the Salinas Valley in Monterey County,

[10] Data compiled from: United States Department of Agriculture. Agricultural statistics. 1943:242. 1943.

and the Santa Maria and Santa Ynez valleys in Santa Barbara County. Besides these designated areas certain other places, such as smaller coastal valleys and parts of the San Joaquin Valley not shown, are climatically adapted to the growing of bean seed.

EFFORTS TO OBTAIN DISEASE-FREE SNAP-BEAN SEED

Over a period of years the center of bean-seed production has moved from east to west. Now a considerable portion of the seed stock grown in the United States originates in Idaho, Montana, Wyoming, Utah, Colorado, and Cali-

Fig. 1.—California areas (shaded portions) of proved adaptability to the growing of snap-bean seed. Other parts of the state may later prove suitable.

fornia, although Michigan and New York still produce large quantities. The establishment of seed production in the West is due largely to the recognition that "clean seed will grow clean beans" (Whetzel, 1908) and that western-grown seed is much more likely to be free of disease than seed grown in humid regions. Though usually much superior, all western seed is not always safe, since, as already pointed out, several inches of rain may fall during the bean-growing season in each of the western seed areas previously mentioned except California.

California-grown Red Kidney bean seed (Smith, 1942) has been so suc-

cessful in the East in eliminating losses from blight and anthracnose that the New York State College of Agriculture has urged the growers to use it exclusively (Hardenburg, 1942). Naturally, too, there is a demand for disease-free seed of other bean varieties.

The discovery that the western seed is, in general, freer of disease than the eastern is not new. The possibilities were being considered in 1908 in connection with anthracnose. Whetzel (1908) argued then that in the West, "since there is no moisture in the air . . . the spores of the fungus cannot be distributed." Muncie pointed out (1917) that "by growing Michigan seed beans in Idaho or California, Michigan can secure clean seed each year." By 1930 it was recognized that "Red Kidney beans grown in California are entirely free from the bacterial blights and that such seed brought to New York has produced healthy fields the first year" (Burkholder, 1930). Recommendations that western seed be used for control of anthracnose and blight were again made by Harter and Zaumeyer (1932). Concerning blight they stated: "Since all western-grown bean seed is not blight-free every year, it is desirable to determine the exact location in which the seed was grown." Later the same authors stated (Harter and Zaumeyer, 1944), in reference to blight, that "the value of clean seed cannot be emphasized too strongly." The Missouri Agricultural Experiment Station has instructed its farmers: "Do not use home-grown seed . . . . Western-grown seed is much freer of disease" (Tucker, 1942). According to the Florida Agricultural Experiment Station, "Seeds free from the halo blight bacteria can be secured only from fields where the disease does not occur . . . . Halo blight has never been reported from California" (Townsend, 1939). Tests at the Louisiana Agricultural Experiment Station since 1937 with California-grown snap-bean seed have shown that such seed consistently produces crops free from anthracnose and blight (Person, 1942); as a result, the amount of certified California-grown seed shipped to Louisiana has increased from 25,600 pounds in 1940 to 85,000 pounds in 1943. In addition to the latter figure, bean seed was grown here by seed firms for delivery to Louisiana without certification.

Later experience at the Louisiana Station (Plakidas, 1943) indicates that "it is . . . not enough to have seed that is *almost* blight-free. To get complete protection against blight it is necessary to plant seed which is *entirely* blight-free. . . . Carefully conducted field tests in Louisiana during the past three years have shown that the California-grown seed was completely blight-free."

Comparisons between California-grown and Michigan-grown bean seed have been made during several seasons in Michigan (Rather and Pettigrove, 1944). It was shown that "seed directly from California has given very good results. However, when grown in Michigan under blight conditions it becomes reinfected in a year or two. Hence, to obtain full value from this procedure new seed should be brought in from California each year."

The recommendations often fail to mention that not all western seed is free from anthracnose and blight. In at least one instance, reported from Virginia, "growers are beginning to lose faith in the recommendation of planting western grown seed, since they are under the impression that they have been planting seed grown in that area, yet have heavy anthracnose infection" (Plant Disease Reporter, 1942*a*).

RECOMMENDATIONS FOR PREVENTION OF ANTHRACNOSE AND BLIGHT

From the national standpoint the prevention of anthracnose and bacterial blight in beans depends upon the combined efforts of the seed grower and the seed user. This means first the production of disease-free, quality seed by the grower, and then its intelligent employment by the user.

Some varieties of snap beans are now being grown in California under the supervision of the California Crop Improvement Association. Certified seed guarantees to the purchaser not only the identity of the variety, but also the quality of the seed and its source of origin. A number of reliable, long-established seed firms also have seed available.

Precautions for Seed Growers in California.—To produce seed consistently free from blight and anthracnose year after year, it is suggested that the following precautions be taken by the seed grower:

1. Produce seed in the driest, most rain-free climate, from seed stocks that have been maintained in the same climate. Suitable areas are delimited on the map in figure 1.

2. Avoid very early or very late plantings that may be subject to rainfall either at the beginning or the end of the season. The driest, most suitable months for growing the seed crop are shown by the rainfall data given in table 1.

3. Do not count on being able to clean up an infected seed stock from some other area by growing it in California for one season only. Anthracnose is probably eliminated in a single season; but it may take several seasons to eliminate bacterial blight completely, even in the absence of secondary spread of the disease.

4. When harvesting, recleaning, and resacking seed avoid mixing disease-free seed with seed from any other source. Just a few infected seeds that slip into a grower's lot of clean seed are enough to destroy all the advantages claimed for clean seed. If the seed is grown in California and is to be sold elsewhere as blight- and anthracnose-free seed, it is recommended that the seed be cleaned and sacked here.

5. Keep free from mosaic the seed fields being used for the production of blight- and anthracnose-free seed. Seed-borne mosaic may neutralize to some extent the benefits obtained from using such seed.

Precautions for Seed Users in Humid Regions.—The user of bean seeds, whether he grows for the green- or the dry-bean market, for the processor, or for home use cannot expect to eliminate blight and anthracnose from his fields merely by securing disease-free seed. In order not to lose all the advantages of noninfected, high-quality seed, the user of bean seeds should adhere to the following precautions:

1. Buy seed on the reputation of the seller, not alone on price. Be prepared to pay a premium price for premium seed.

2. Be sure the seed was grown in the rain-free areas outlined herein during the dry, summer period, from seed stocks also grown in these areas, and that the seed is as represented.

3. Avoid contamination of the seed with other seed after its delivery. A

few infected seeds left in the seed planter from the previous season, for example, would be sufficient to initiate disease in the field.

4. Do not plant clean seed on land that was in beans the previous season. If possible, plan a three- or four-year rotation between bean crops. Crop rotation is important in preventing these and other diseases.

5. Avoid planting clean seed adjacent to bean fields where crop rotation and the use of clean seed are not practiced. Isolation from near-by fields is not always possible but is desirable.

6. Guard against bringing infection into the field from a near-by field. The bacterial or fungus ooze that adheres to clothing and machinery during its passage through a diseased field while the foliage is wet is sufficient under these same conditions to transfer the infection into a clean field.

7. Practice sanitation in and around the field. Bacterial blight can be spread from a single infected plant of the wild bean (*Strophostyles helvola*), or of the kudzu-vine. An infected volunteer bean also may start the disease in a field.

8. Avoid saving seed, even from an apparently clean crop. Under rainy conditions these diseases gradually find their way back into the seed. In practice, if seed is to remain consistently free from blight and anthracnose, it must be grown continually in a rain-free climate.

RELATIVE COSTS OF PRODUCING SNAP-BEAN SEED AND FIELD BEANS

Obstacles to the production of snap-bean seed in California are the higher costs of production and the relatively higher price of competing beans. High yields have made Idaho a leading producer of this seed. Only on the basis of consistent freedom from bacterial blights and anthracnose can the California beans compete. The returns per acre of beans (all varieties) may be compared for Idaho and California from data taken from the United States Department of Agriculture.[11] A computation of returns was obtained by multiplying the average yield by the average price. For the five-year period 1938 to 1942 the returns were:

State	5-year-average yield, in pounds per acre	5-year-average return per 100 pounds, in dollars	Total price, in dollars
California	1,303	4.38	57.07
Idaho	1,452	3.05	44.29

The higher returns per acre for California are due to the higher prices of large and small limas and other beans not grown in Idaho. Snap beans in California would have to compete with other varieties in the state which are grown for dry beans and with prices of competing snap-bean seed-producing states.

Snap-bean seed costs more to produce than seed of competing bean crops because it must be kept free from mixture with other beans in harvesting and recleaning. Some snap-bean varieties are more difficult to thresh than ordinary dry beans. In such varieties as Giant Stringless Greenpod, Tendergreen, Kentucky Wonder, and the Refugee types, the fleshy pods shrink tightly against

[11] 1938, 1939 data from: United States Department of Agriculture. Agricultural statistics. **1940**:302. 1940.
1940 data from: United States Department of Agriculture. Agricultural statistics. **1942**:354. 1942.
1941, 1942 data from: United States Department of Agriculture. Agricultural statistics. **1943**:247. 1943.

TABLE 2

SEED YIELDS OF SNAP-BEAN VARIETIES AS COMPARED WITH THOSE OF RED KIDNEY FIELD BEANS IN THREE CALIFORNIA DISTRICTS

Variety	Accession no.	Marysville								Clements		Sutter Basin		Average percentage of Red Kidney	Trials
		1938		1939		1940		1941		1940		1940			
		Amount per acre	Percentage of Red Kidney	Amount per acre	Percentage of Red Kidney	Amount per acre	Percentage of Red Kidney	Amount per acre	Percentage of Red Kidney	Amount per acre	Percentage of Red Kidney	Amount per acre	Percentage of Red Kidney		
		pounds	*per cent*	*pounds*	*per cent*	*pounds*	*per cent*	*pounds*	*per cent*	*pounds*	*per cent*	*pounds*	*per cent*	*per cent*	*number*
Red Kidney	7811	2,669	100	1,880	100	2,308	100	2,449	100	2,360	100	2,117	100	100	6
Michigan Dark Red Kidney	8099	2,331	87	1,929	103	1,404	61	2,248	92	2,279	97	1,889	89	88	6
Stringless Black Valentine	8600	...	...	1,563	83	1,752	76	2,007	82	2,356	100	1,961	93	87	5
Giant Stringless Greenpod	7982	1,720	64	1,430	76	2,083*	90	2,353*	96	2,570	109	1,771	84	86	6
Sure Crop Wax	7961	1,915	72	1,730	92	2,034	88	2,122	87	2,416	102	1,739	82	87	6
Bountiful	7962	1,980	74	1,830	97	1,269	55	1,857	76	2,159	92	1,700	80	79	6
Davis Stringless Wax	8601	.....	...	1,478	79	1,564	68	1,897	78	....	...	.....	...	75	3
New Stringless or Tendergreen	8599	.....	...	1,340	71	1,778	77	2,120	87	.....	...	.....	...	78	3
Idaho Mosaic Resistant Refugee	8650	...	...	.....	...	2,422	105	2,018	82	.....	...	.....	...	94	2
U. S. No. 5 Refugee	8649	.....	...	...	..	2,073	90	1,772	72	.....	...	.....	...	81	2
Average of nine varieties		.....	...	.....	...	.....	...	.....	...	.....	...	.....	...	84	..

* Average of two stringless selections.

the seed; this increases the cost of threshing. Black Valentine, Sure Crop Wax, Bountiful, and certain others, however, thresh as easily as the common kidney bean. Pole varieties like Kentucy Wonder are more difficult to thresh than bush varieties like Sure Crop Wax. Some snap beans are also more susceptible to damage from red spider and bean thrips.

Yield tests have been made with a number of snap beans in comparison with Red Kidney, which yields about 10 per cent less than other field beans. Table 2 presents data from yield trials of four years from Marysville in Yuba County and one year each from Clements in San Joaquin County and Sutter Basin in Sutter County. According to these figures, the average yield

TABLE 3

SEED YIELDS OF ADDITIONAL SNAP-BEAN VARIETIES AS COMPARED WITH YIELD OF RED KIDNEY FIELD BEANS IN SINGLE-ROW REPLICATED PLOTS, MARYSVILLE, 1941

Variety	Accession no.	Amount per acre	Percentage of Red Kidney
		pounds	*per cent*
Red Kidney	7811	3,153	100
Burpee's Fordhook Favorite	8547	1,855	59
Roger's Stringless Green Refugee	8648	2,249	71
French Horticultural	8545	2,218	70
Burpee's Stringless Greenpod	8549	2,810	89
Round Podded Kidney Wax	8651	1,486	47
Plentiful	8554	2,278	72
Keeney's Stringless Refugee	8551	2,297	73
Average of seven varieties	....	.....	69

of bush snap beans is about 84 per cent that of Red Kidney. Michigan Dark Red Kidney is included in this list because there is some demand in the eastern states for disease-free seed of this variety. Table 3 lists seven additional varieties that were tested only one year in single-row replicated plots. In general, the comparative yields with Red Kidney are lower. One reason may be that the plots were small: the border effect of adjacent varieties was not entirely eliminated.

Since the nine varieties listed in table 2 average only 84 per cent of Red Kidney in yield, the price differential for growers should be 119 per cent. In parts of the state where the commercial dry-bean variety is Pink, Small White, or small limas, the differential should be even greater if the snap beans are to compete effectively, because these varieties yield more than the Red Kidney.

To the usual cost of production must be added the extra time and expense necessary for a seed crop. Red Kidney bean growers estimate that it costs $2.00 per hundred more to grow this variety for seed than for the dry-bean market. Since the whole outlet of snap beans must be through the seed market, these increased costs must be considered.

DISCUSSION

Since the production of clean seed, year after year, depends so directly upon freedom from rainfall, even in the California areas of lowest relative precipitation the seed beans should be grown during the driest months. (See

section "Climate in Relation to Production of Clean Seed" and fig. 1.) Plantings made very much too early or too late may run into the last spring or first fall rains. If infected seed of eastern origin were planted, there would be some danger of infection. Though primary infection may be unimportant under dry western conditions from the standpoint of seed contamination, it is wholly to be avoided where possible. The maintenance of seed stocks in California would operate against the spread of these seed-borne diseases wherever this seed is used.

No claim has been made that bacterial blight and anthracnose cannot or do not occur here at times. Both have been seen in a few localized instances, when infected seed has been planted out of season and the plants subjected to some rainfall, or when there is overhead sprinkling. Anthracnose and blight have not been found in seed fields planted at the proper time in the areas of seed-bean production in California, even though diseased seed stocks from the East have sometimes been used. If primary infection takes place it would not ordinarily be detected, because of the complete lack of any secondary spread; and such infection is probably largely self-eliminated under California conditions.

The rainless summers in bean areas here prevent the development and spread of anthracnose and blight, together with the infection of beans and related crops by other wet-weather diseases. These other diseases—for example, pod blight of lima bean, caused by *Diaporthe phascolorum* (Cke. and Ell.) Sacc., and scab of cowpea, caused by *Cladosporium vignae* Gardner—are practically nonexistent in California. In addition the important seed-borne virus of beans, common bean mosaic, caused by bean virus 1, is not spread under most California conditions to the extent that it is spread elsewhere. According to the United States Department of Agriculture, in reference to mosaic, the "best method of preventing the disease is by the introduction of seed stock from regions reasonably free from the malady. . . . Comparatively clean seed is produced along the Pacific coast" (Harter and Zaumeyer, 1932). The mosaic of cowpea is practically unknown in California.

Clean seed is not in itself, however, a guarantee against blight and anthracnose if the planting is made on a field still bearing refuse of a diseased bean crop. Nor will clean seed alone prevent blight if it is planted next to a diseased field or near infected volunteer beans or weed hosts. With increasing amounts of the kudzu-vine being grown in some southern states, consideration must be given to the planting of beans next to this blight-susceptible plant. The occurrence of the kudzu-vine as an escape that has established itself in an area must also be reckoned with along with any other weed hosts of blight (Gardner, 1924) that may be present. No program to prevent seed-borne diseases can be made successful solely through the use of clean seed; the grower must practice crop rotation and eliminate such other carryover sources and local transference of infection as may occur.

A bean-seed industry in California, in which disease-free stocks are maintained for use in all parts of the country, can do much toward eliminating the serious losses in the United States from anthracnose and blight, and also toward reducing the loss from mosaic. Since the production of such seed costs somewhat more per pound in California than in certain other areas, the user

must be charged slightly more than he is accustomed to pay. Since, however, the price of seed is a minor item in the cost of growing beans, this small additional cost appears to be insignificant—in fact, very cheap insurance against diseases that may wipe out an entire crop just before harvest.

SUMMARY

There is evidence that anthracnose and blight are the most important diseases of bean in the United States from the standpoint of losses over a period of years.

Anthracnose and blight are seed-borne, the causal organisms being carried abundantly in seed harvested from infected fields. Even where very small amounts of either of these diseases are present, a disastrous loss may result when the seed from such a field is planted under certain climatic conditions.

Attempts have been made to control anthracnose and blight by various seed treatments, by the application of sprays and dusts in the field, and by the development of resistant varieties. None of these methods, however, have yet controlled these diseases in humid regions.

Apparently, the most promising and practical method of controlling anthracnose and blight is to prevent them through the use of disease-free seed coupled with crop rotation.

Since these diseases are wet-weather troubles, seed grown in the West is more likely to be free of infection than seed from the East or Midwest. Summer rains are sufficient, however, in certain western states to permit the development and spread of blight in some seasons, although most western seed may be free of anthracnose.

Anthracnose and blight do not occur in bean-seed crops grown in California during the dry, almost rain-free summers. Weather records show that during the bean-growing season California has far less rainfall (an average total of about ½ inch) than any of the other bean-growing states (averages of 3 to 13 inches) and that the lack of summer rainfall in this state is consistent from season to season despite great variability in the amounts of annual rainfall.

A map presented (fig. 1) shows the location and limits of the disease-free areas in California suited to the production of snap-bean seed. These areas appear adequate to meet all demands is this country for anthracnose-free and blight-free snap-bean seed.

Other advantages by California-grown seed, besides freedom from anthracnose and blight, are the low incidence of seed-borne mosaic and of field hybridization.

Records of the success of California-grown field and snap-bean seed in eliminating losses in eastern and southern states from anthracnose and blight are cited for New York, Michigan, and Louisiana.

Because of low yields and high production costs, snap-bean seed grown in California must sell at a higher price per pound than seed from certain other states. This increased cost is small, however, and represents exceedingly cheap insurance against disastrous crop losses from anthracnose and blight.

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[12] A mimeographed pamphlet issued by the United States Department of Agriculture, Bureau of Plant Industry. Early issues appeared under the name *Plant Disease Bulletin*. Because the collaborators in these reports are not always mentioned, it has proved convenient to list the items under *Plant Disease Reporter* in chronological order.

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